

METHODS FOR ENHANCING THE CONSOLIDATION STRENGTH OF RESIN COATED PARTICULATES

Background of the Invention

1. Field of the Invention.

[0002] The present invention involves enhancing the conductivity of subterranean propped fractures penetrating formations while controlling proppant flowback. More particularly, the present invention relates to improved consolidation performance of resin-coated proppants and their use in controlling proppant flowback.

2. Description of Related Art.

[0003] A subterranean formation may be treated to increase its conductivity by hydraulically fracturing the formation to create or enhance one or more cracks or “fractures.” Such hydraulic fracturing is usually accomplished by injecting a viscous fracturing fluid into the subterranean formation at a rate and pressure sufficient to cause the formation to break down and produce one or more fractures. The fracture or fractures may be horizontal or vertical, with the latter usually predominating, and with the tendency toward vertical fractures increasing with the depth of the formation being fractured. The fracturing fluid is generally a highly viscous gel, emulsion, or foam that may comprise a particulate material often referred to as proppant. In some fracturing operations, commonly known as “water fracturing” operations, the fracturing fluid viscosity is somewhat lowered and yet the proppant remains in suspension because the fracturing fluid is injected into the formation at a substantially higher velocity. Whether a highly viscous fluid is used or a less viscous fluid with a higher velocity, proppant is deposited in the fracture and functions, *inter alia*, to hold the fracture open while maintaining conductive channels through which produced fluids can flow upon completion of the fracturing treatment and release of the attendant hydraulic pressure.

[0004] In order to prevent the subsequent flowback of proppant and other unconsolidated particulates with the produced fluids a portion of the proppant introduced into the fractures may be coated with a hardenable resin composition. When the fracturing fluid, which is the carrier fluid for the proppant, reverts to a thin fluid the resin-coated proppant is deposited in the fracture, and the fracture closes or partially closes on the proppant. Such fractures apply pressure on the

resin-coated proppant particles, causing the particles to be forced into contact with each other while the resin composition hardens. The hardening of the resin composition under pressure brings about the consolidation of the resin-coated proppant particles into a hard permeable mass having compressive and tensile strength that hopefully prevents unconsolidated proppant and formation sand from flowing out of the fractures with produced fluids. Flowback of the proppant or formation fines with formation fluids is undesirable as it may erode metal equipment, plug piping and vessels, and cause damage to valves, instruments, and other production equipment, and ultimately reduce the potential production of the well.

[0005] Most of the resin on resin pre-coated proppant is already cured. This partially cured resin needs to be softened either by temperature or an activator (as in the case of low temperature wells) so that the resin can be wedged together as the resin coated proppant grains contact one another. In addition to the softening effect of resin coated on the proppant, closure stress is required to cause grain-to-grain contact. Without grain-to-grain contact, adequate consolidation of proppant pack generally will not occur.

SUMMARY OF THE INVENTION

[0006] The present invention involves enhancing the conductivity of subterranean propped fractures penetrating formations while controlling proppant flowback. More particularly, the present invention relates to improved consolidation performance of resin-coated proppants and their use in controlling proppant flowback.

[0007] Some embodiments of the present invention provide methods of controlling proppant flowback from a fracture in a subterranean zone comprising the steps of providing resin coated proppant; providing tackifying composition; coating the tackifying composition onto at least a portion of the resin coated proppant to create tackyfried resin coated proppant; introducing the tackyfried resin coated proppant into a subterranean fracture; and, allowing the tackyfried resin coated proppant to substantially cure.

[0008] Other embodiments of the present invention provide methods of fracturing a subterranean formation comprising the steps of providing a fracturing fluid; placing the fracturing fluid into a subterranean formation at a pressure sufficient to create or extend at least one fracture therein; providing tackyfried resin coated proppant: placing the tackyfried resin coated proppant into the subterranean fracture; and, allowing the tackyfried resin coated proppant to substantially cure.

[0009] The objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments that follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0010] The present invention involves enhancing the conductivity of subterranean propped fractures penetrating formations while controlling proppant flowback. More particularly, the present invention relates to improved consolidation performance of resin-coated proppants and their use in controlling proppant flowback.

[0011] The methods of the present invention act, *inter alia*, to enhance the consolidation strength of resin coated proppant (hereinafter "RCP"). RCP is a proppant material that is coated with resin and allowed to partially cure so that it can be, *e.g.*, conveniently stored and transported. Some embodiments of the methods of the present invention comprise coating a tackifying material onto RCP and then using that tackified RCP in a subterranean application such as hydraulic fracturing, frac-packing or vent-screen gravel packing.

[0012] Proppant particles used in accordance with the present invention to create RCP are generally of a size such that formation particulates that may migrate with produced fluids are prevented from being produced from the subterranean zone. Any suitable proppant may be used, including graded sand, bauxite, ceramic materials, glass materials, walnut hulls, polymer beads and the like. Generally, the proppant particles have a size in the range of from about 4 to about 400 mesh, U.S. sieve series. In some embodiments of the present invention, the proppant is graded sand having a particle size in the range of from about 10 to about 70 mesh, U.S. Sieve Series. Suitable commercially available RCP materials include but are not limited to pre-cured resin-coated sand, curable resin-coated sand, curable resin-coated ceramics, single-coat, dual-coat, or multi-coat resin coated sand, ceramic, or bauxite. Some examples available from Borden Chemical, Columbus, Ohio, are "XRT™ CERAMAX P," "CERAMAX I," "CERAMAX P," "ACFRAC BLACK," "ACFRAC CR," "ACFRAC SBC," "ACFRAC SB," and "ACFRAC LTC." Some examples available from Santrol, Fresno, Texas, are "HYPERPROP G2," "DYNAPROP G2," "MAGNAPROP G2," "OPTIPROP G2," "SUPER HS," "SUPER DC," "SUPER LC," and "SUPER HT."

[0013] Compositions suitable for use as tackifying compounds in the present invention comprise any compound that, when in liquid form or in a solvent solution, will form a non-hardening coating upon a RCP. A particularly preferred group of tackifying compounds comprise polyamides that are liquids or in solution at the temperature of the subterranean formation such that they are, by themselves, non-hardening when introduced into the

subterranean formation. A particularly preferred product is a condensation reaction product comprised of commercially available polyacids and a polyamine. Such commercial products include compounds such as mixtures of C₃₆ dibasic acids containing some trimer and higher oligomers and also small amounts of monomer acids that are reacted with polyamines. Other polyacids include trimer acids, synthetic acids produced from fatty acids, maleic anhydride and acrylic acid and the like. Such acid compounds are commercially available from companies such as Witco Corporation, Union Carbide, Chemtall, and Emery Industries. The reaction products are available from, for example, Champion Technologies, Inc. and Witco Corporation. Additional compounds which may be utilized as tackifying compounds include liquids and solutions of, for example, polyesters, polycarbonates and polycarbamates, natural resins such as shellac and the like. Suitable tackifying compounds are described in U.S. Patent Number 5,853,048 issued to Weaver, *et al.* and U.S. Patent Number 5,833,000 issued to Weaver, *et al.*, the relevant disclosures of which are herein incorporated by reference.

[0014] In some embodiments of the present invention, the RCP is coated with a tackifying compound on-the-fly. The term “on-the-fly” is used herein to mean that a flowing stream is continuously introduced into another flowing stream so that the streams are combined and mixed while continuing to flow as a single stream as part of the on-going treatment. Such mixing can also be described as “real-time” mixing. On-the-fly mixing, as opposed to batch or partial batch mixing, may reduce waste and simplify subterranean treatments. This is due, in part, to the fact that if the components are mixed and then circumstances dictate that the subterranean treatment be stopped or postponed, the mixed components may quickly become unusable. By having the ability to rapidly shut down the mixing of streams on-the-fly, such waste can be avoided, resulting in, *inter alia*, increased efficiency and cost savings.

[0015] Figure 1 illustrates one embodiment of an on-the-fly mixing method of the present invention. Container 10 holds particulate matter such as RCP. Conveyance means 11 can be any means known in the art for conveying particulate material, in one embodiment of the present invention, conveyance means 11 comprises a conveyor belt or a sand screw. Conveyance means 11 transports proppant to container 30. Container 20 holds tackifying compound and line 21 transports the tackifying compound to container 30. Control of the total and relative amounts of tackifying compound is achieved through the use of valve 22 on line 21 and of RCP through the control of conveyance means 11. Inside container 30, the particles from container 10 are coated

with tackifying agent from container 20 to form tackified RCP. The coated particles exit container 30 via conveyance means 31. Where conveyance means 31 is a sand screw, the RCP may be coated with the tackifying agent by the auger action of the sand screw itself.

[0016] Where it is desirable to immediately use the tackified RCP in a subterranean treatment, it may be transported by conveyance means 31 directly from container 30 to blender tub 40. In one embodiment, the transport of tackified RCP from container 30 to blender tub 40 is computer-controlled to ensure accurate metering and to allow for a rapid shutdown of on-the-fly mixing when necessary. Also transported to blender tub 40 is a servicing fluid, such as a fracturing fluid or gravel packing fluid, from container 50 through transport line 51. The servicing fluid from container 50 may be transported to blender tub 40 by any means known in the art. In one embodiment, the transport of servicing fluid from container 50 to blender tub 40 is computer-controlled to ensure accurate metering and to allow for a rapid shutdown of on-the-fly mixing when necessary. Such computer control may be achieved, in part, by making valve 52 a computer-controlled valve. Inside blender tub 40, the servicing fluid is substantially mixed with tackified RCP to form a blended composition suitable for use in subterranean fractures.

[0017] When the tackified RCP of the present invention is used in a subterranean fracturing operation, any fracturing fluid known in the art may be used, including viscosified treatment fluids, aqueous gels, emulsions, and other suitable fracturing fluids. Where used, the aqueous gels are generally comprised of water and one or more gelling agents. Also, where used, the emulsions may be comprised of two or more immiscible liquids such as an aqueous gelled liquid and a liquefied, normally gaseous fluid, such as nitrogen. The preferred fracturing fluids for use in accordance with this invention are aqueous gels comprised of water, a gelling agent for gelling the water and increasing its viscosity, and optionally, a cross-linking agent for cross-linking the gel and further increasing the viscosity of the fluid. The increased viscosity of the gelled or gelled and cross-linked fracturing fluid, *inter alia*, reduces fluid loss and allows the fracturing fluid to transport significant quantities of suspended proppant particles. The fracturing fluids may also include one or more of a variety of well-known additives such as breakers, stabilizers, fluid loss control additives, clay stabilizers, bactericides, and the like.

[0018] The methods of the present invention may be particularly useful in situations where the subterranean formation places little or no closure stress on resin coated proppant placed therein. Industry research has shown that hydraulic fractures may not completely close

during the first 24 hours after a hydraulic fracture stimulation treatment. In fact, some fractures may not completely close for ninety days or longer. Such slow closing of the fractures affects the ultimate consolidation strength of resin coated proppant packs because without the application of closure stress, the grain-to-grain contact may be insufficient to effect consolidation. In that situation, once the closure stress is applied, the resin coating the proppant may have already cured.

[0019] The tackifying composition may act, *inter alia*, to enhance the grain-to-grain contacts between individual RCP particles. Moreover, the tackifying composition is believed to soften the partially cured resin on the RCP. This dual action of the tackifying composition may improve the final consolidation strength of a proppant pack made using the tackified RCP of the present invention.

[0020] In one embodiment of the methods of the present invention, RCP is substantially coated with a tackifying composition to form tackified RCP. The tackified RCP is then placed in a subterranean zone having one or more fractures therein and allowed to cure and consolidate into one or more high-strength permeable packs.

[0021] To facilitate a better understanding of the present invention, the following examples of some of the preferred embodiments are given. In no way should such examples be read to limit the scope of the invention.

EXAMPLES

Example 1

[0022] Uncoated (control) RCP material was mixed with various fracturing fluids, stirred, and then packed into a brass chamber and allowed to cure with no applied pressure and, after a period of time, the unconfined compressive strength was determined. The same procedure was followed for the same RCP coated with SandWedge™ NT tackifying composition that is commercially available from Halliburton Corporation, Houston Texas.

Table 1: Effect of Cure Tackifying Agent on RCP Consolidation Strength

Amount of tackifying agent (% volume / weight) on RCP	Fracturing Fluid	Stir Time (minutes)	Cure time	Unconfined Compressive Strength (psi)
0% on 20/40 RCP	30# Linear Carboxymethyl Guar (CMG)	60	1 hr at 300°F	85
2% on 20/40 RCP	30# Linear CMG	60	1 hr at 300°F	325
2% on 20/40 RCP	30# Linear CMG	0	1 hr at 300°F	280
2% on 20/40 RCP	30# Linear CMG	0	3 hrs at 300°F	330
2% on 20/40 RCP	30# Linear CMG	0	20 hrs at 300°F	355
0% on 20/40 RCP	30# Crosslinked CMG	60	1 hr at 300°F	50
2% on 20/40 RCP	30# Crosslinked CMG	60	1 hr at 300°F	450
0% on 16/30 RCP	35# Linear Hydropropyl guar (HPG)	0	24 hrs at 250°F	0
2% on 16/30 RCP	35# Linear HPG	0	24 hrs at 250°F	90

[0023] The results in Table 1 illustrate that proppant packs created from RCP coated with a tackifying composition yield compressive strengths higher than proppant packs created from uncoated RCP.

[0024] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.